NASA TECHNICAL
MEMORANDUM

NASA TM X-53086

JULY 14, 1964

NASA TM X-53086

PREDICTED ACOUSTIC EFFECTS AT MSFC OF THE STATIC TEST FIRING OF THE ADVANCED SATURN S-IC

by RICHARD N. TEDRICK
Test Laboratory

NASA

George C. Marshall
Space Flight Center,
Huntsville, Alabama

TECHNICAL MEMORANDUM X-53086

PREDICTED ACOUSTIC EFFECTS AT MSFC OF THE STATIC TEST FIRING OF THE ADVANCED SATURN S-IC

By

Richard N. Tedrick

George C. Marshall Space Flight Center
Huntsville, Alabama

ABSTRACT

29010

This report presents the overall and octave band sound pressure level spectra which have been predicted to result from the static test firing of the S-IC stage booster for the Saturn V vehicle. Acoustic hazard and damage criteria are discussed and applied to the predicted sound pressure levels for the S-IC.

The effects of the acoustic directivity and test stand orientation are explained. The overall acoustic implications of static testing the S-IC at Marshall Space Flight Center are discussed in terms of their effects upon surrounding installations and communities.

Author

NASA-GEORGE C. MARSHALL SPACE FLIGHT CENTER

NASA - GEORGE C. MARSHALL SPACE FLIGHT CENTER

TECHNICAL MEMORANDUM X-53086

PREDICTED ACOUSTIC EFFECTS AT MSFC OF THE STATIC TEST FIRING OF THE ADVANCED SATURN S-IC

By

Richard N. Tedrick

TEST LABORATORY
RESEARCH AND DEVELOPMENT OPERATIONS

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

TECHNICAL MEMORANDUM X-53086

PREDICTED ACOUSTIC EFFECTS AT MSFC OF THE STATIC TEST FIRING OF THE ADVANCED SATURN S-IC

SUMMARY

This report presents the overall and octave band sound pressure level spectra which have been predicted to result from the static test firing of the Advanced Saturn S-IC. The predicted peak frequency in the acoustic mid-field is in the 16 cycles per second octave, while the overall sound level is expected to rise 7 decibels. These predictions are applied to recognized acoustic hazard and damage criteria.

The effects of the acoustic directivity and test stand orientation are explained. The overall acoustic implications of static testing the S-IC at Marshall Space Flight Center are discussed in terms of their effects upon surrounding installations and communities.

INTRODUCTION

The rapid increase in the size of space vehicle boosters during the last few years and the resultant increase in the noise levels generated during the static test firings of these engines has made the prediction and control of sound generation an important phase of rocketry. This has been especially true since the advent of the Saturn family of space vehicles because it was found that not only was the Saturn S-I the world's largest and most powerful tool for extraterrestial investigation but it was also the largest and most powerful man-made, steady-state noise generator. Occasionally, during the testing of the Saturn S-I vehicle at Marshall Space Flight Center, this noise has been propagated across the Redstone Arsenal area and into the surrounding civilian communities. Because of the meteorological factors at the time of firing, this acoustical energy has sometimes been concentrated into relatively small zones in business or residential areas. Such occurrences have heightened the interest in determining what may be the acoustic consequences of static firing even larger rocket vehicles, whether they are to be fired at MSFC or elsewhere. Since the first of these larger space vehicles which will be tested is the Advanced Saturn S-IC, it is best to consider in detail at this time what the effects of such testing may likely be.

To predict the effects of such tests, both Saturn S-I static test acoustic data and limited model studies have been utilized. These, it is felt, are useful bases for extrapolation to full-scale, large thrust static tests. These extrapolations, however, only represent the present state-of-the-art thinking about a specific type of test configuration and should be applied to other types with extreme caution.

BACKGROUND

Most sources of sound are vibrating bodies which cause disturbances in the air. Other sources, such as the Saturn booster, generate sound by inserting rapidly moving hot gases into the atmosphere. Such sounds have become relatively familiar to most Americans with the advent of both military and commercial turbojet aircraft. Rocket noise is not too unlike that from a turbojet, except that it is usually lower pitched than the jet's distinctive whine.

The noise environments which can be expected from the test firing of large rockets have now become important considerations in planning test sites and the surrounding supporting communities. One can consider the problem to consist of three distinct parts, each of which must be solved to achieve a complete solution. The first of these is the noise source itself. The Saturn generates a tremendous volume of exhaust gases moving at supersonic velocities. These gases moving through a relatively still atmosphere cause large amounts of low frequency sound to be generated. Part of the answer to reducing noise levels might lie in muffling the noise produced at the test stand, thus helping to lower the amount of energy originally radiated into the atmosphere. However, for the present, as larger and larger boosters are being developed, this cannot be suggested as the entire solution to the problem.

The second aspect of the noise situation concerns the ability of the sound to reach the civilian communities which always spring up around any major testing site. The most obvious solution to this is simply to purchase all of the land around the base for about twenty miles. Unfortunately, this is not often feasible since most of the bases were begun a few years ago when missiles and missile sounds were not nearly so large. As a result, small cities were built up within a few miles of most launch and static test facilities.

Another solution to this matter of the transmission of missile sounds concerns the role of weather in such transmission. It is possible to greatly lower the sound level at a point several miles distant from a sound source simply by choosing the meteorological conditions under which the test is to be performed. Similarly, the sound pressure levels can be raised materially by good propagation conditions at the time of a test. It is in this particular field where the best results can be anticipated for noise control.

The third and last factor of the noise problem lies with the "receiver", or the individual who will be exposed to the noise and to its effects. A large part of the question can be resolved by an examination of the attitude that people on the receiving end of the propagation path have toward the noise. For instance, while the sound from a rocket test may be no louder than that created when the man next door used his power lawn mower, still if the test is held at 2 a.m., it may be expected that the reaction will be unfavorable. Hence, good public relations will help to solve the noise problem.

Both the guided and unguided rocket vehicles have been, since their inception, primarily military weapons. With the impetus of wartime development, there usually was little concern with civilian discomfort. Also, since the early rockets were relatively small, so were the sounds. The amount of unused "buffer" land ordinarily utilized around military installations to maintain reasonable military security proved in most instances to be quite satisfactory to attenuate the sound from rocket tests. However, the development in recent years of large rockets such as the Jupiter, Atlas, and Titan has ensured that occasionally some nearby residents would be jolted out of their sleep. Nonetheless, the importance of the programs to the national defense precluded any major shifts in either test sites or schedules just because of the noise.

With the creation of the National Aeronautics and Space Administration, a large civilian rocket program was undertaken for the first time, which, because of its very nature, must remain sensitive to community reaction. Assigning the responsibility for large booster development to Marshall Space Flight Center focused the noise problem from these vehicles on the community supporting this installation. Since the city of Huntsville, Alabama, lies five to ten miles northeast of the Saturn static test tower, the noise from such static tests has on occasion not only been heard, but felt, in Huntsville.

It was found that this has been due primarily to the weather conditions under which these tests have been performed. When strong temperature inversions have been reinforced by winds toward the city, the sound is actually focused meteorologically much in the same manner as sunlight is focused by a magnifying glass. This can result in sound pressures in both the business and residential areas of Huntsville of up to above one hundred times normal, (i.e., the sound pressure levels will be increased by 40 decibels). However, exactly opposite conditions have also existed and at those times not even a whisper of the Saturn test was heard.

It has also been learned from experience that the townspeople are not nearly so alarmed or jolted when they have been forewarned. Now it has become standard procedure to announce via the local newspaper, radio, and television stations when a test will be held.

Generally, it may be said that the larger the space vehicle which is being tested, the larger is the amount of sound which is radiated into the atmosphere. However, there are two additional factors which greatly affect the response which may be anticipated from the surrounding communities. One of these is the frequency content of engine noise. It has been shown that as thrust of the rocket engine goes up, the peak frequency goes down. (Ref. 1) This affects the sound level at long ranges because the lower frequencies do not attenuate as rapidly; thus a larger percentage of the original sonic energy is left to disturb outlying areas. Also, as the energy peak drops in frequency, additional energy is put into the subaudible range. Because it is these lower frequencies that rattle windows and shake buildings, the "alarm level" is expected to rise with larger boosters.

Another factor affecting the amount of acoustic energy which reaches the surrounding areas is what is known as the "directivity" of the source. This is simply an index of the relative amounts of energy which are directed by the source itself in each direction. Contributing to this are not only the rocket engine and exhaust velocity parameters but also the shape and configuration of the flame deflector and test tower. After the sound has been radiated into the atmosphere, several things can happen:

1. The sound can be propagated normally as in a still room or large stadium where the effects of wind and temperature are negligible (as on a very still and quiet morning).

2. It can be directed into the upper atmosphere to be dissipated.

3. It can be directed at one or more locations on the earth's surface.

Until recently these effects have been of only academic interest, but with the advent of the large rocket engine test program, a great amount of effort has gone into trying to understand how and why these things happen. Marshall Space Flight Center scientists have developed methods for forecasting these conditions and for locating the areas which may be adversely affected by returning sound.

By determining the meteorological conditions which exist at test time, it is possible to define the boundaries of the focal areas within the accuracy limits placed upon the problem by the meteorological data acquisition techniques.

If any cities or any other sensitive areas fall within these boundaries, the test can be postponed until such time as those conditions no longer exist. By use of long-range weather forecasting techniques, the number of times static tests need to be postponed can be greatly reduced.

ESTIMATION OF SOURCE POWER LEVELS

The major acoustical effect of testing larger boosters will not be the result of any spectacular rises in the overall sound pressure level (SPL) at the source. Indeed, it is anticipated that the overall SPL in the test area for the seven and one-half million-pound thrust Saturn S-IC vehicle test will be only seven decibels (referenced to 0.0002 microbar) over that for the Saturn S-I. However, there will be another problem. The larger thrust vehicle will generate sound having a much larger low frequency content. Since the attenuation, because of atmospheric effects (in decibels per linear measure) is approximately proportional to the square of the frequency, this lower-frequency sound will travel further. Thus, it may be seen that tests of larger space vehicles will result in higher sound pressure levels in the surrounding communities for two reasons; (1) slightly higher sound power generated at the source, and (2) less attenuation due to distance.

One approximate method of calculating the overall sound pressure levels involves the determination of the anticipated power (P_m) of the rocket engine or cluster.

This power is proportional to the amount of mechanical power available from the rocket engine. Since this quantity is usually expressed as the time rate of change of the kinetic energy of the exhaust gases, this relationship may be expressed in equation form as:

$$P_m \approx \frac{dE}{dt} \qquad (1)$$

where P_m is the acoustic power in gram-meters/second and E is the kinetic energy of the existing exhaust gases in gram-meters. Since

$$E = \frac{Mv^2}{2g} \qquad (2)$$

where M is the mass of the exhaust gases in grams and v is the expanded jet velocity in meters per second.

Therefore, for a constant exit velocity

$$\frac{dE}{dt} = \frac{1}{2} \frac{v^2}{g} \frac{dM}{dt} \tag{3}$$

However, the time rate of change of the momentum (Mv) of the exhaust gases is by definition the thrust (T), the above equation can be written:

$$\frac{dE}{dt} = \frac{1}{2} \frac{vT}{g} \tag{4}$$

Now assuming a proportionality (a conversion or efficiency factor) constant (η) Equation 1 becomes'

$$P_m = \eta \frac{dE}{dt} \tag{5}$$

or in another form

$$P_m = \frac{1}{2} \eta \frac{Tv}{g} \tag{6}$$

For most large rocket firings, the acoustic efficiency factor (η) has been found to equal about 0.005 (one-half per cent). Having no reason to think otherwise, it may be reasonable to assume a similar efficiency for even larger vehicles tested under approximately equal conditions.

It can be shown (Ref. 1) that, ignoring excess attenuation and assuming perfect hemispherical radiation,

$$SPL = PWL - 20 \log r - 8 \tag{7}$$

where r is expressed in meters and the sound pressure level (SPL) is in decibels re: 0.0002 microbars. This can be rewritten as:

$$SPL = 10 \log \eta + 10 \log (1/2) \frac{Tv}{P_o} - 20 \log r - 8 \tag{8}$$

where P_o is the reference power power level 10^{-13} watts and r is the radial distance from the source in meters.

Using this method, it was estimated several years ago (Ref. 2) that the acoustic power (P_m) of the single F-1 engine might be expected to be 3.25×10^7 watts. The acoustic power (PWL) level then would be:

$$PWL = 10 \log (3.25 \times 10^7) + 130 \text{ dB} = 205.0 \text{ dB}$$

The actual measured value of the power level for the single F-1 was found to be 204 to 206 decibels (Ref. 3). This agreement attests to the reliability of the analytical method, at least for large booster systems. It should be recalled, however, that this agreement between predicted and measured values was made upon the basis of a rigidly inflexible test stand configuration. Should it ever be necessary to change this, the results might not be so dependable.

CALCULATION OF NOISE SPECTRUM PEAK

Assuming (Ref. 4, page 658) that the peak frequency (f_{max}) in cycles per second of the noise spectrum at a given range from the vehicle is given by the following equation:

$$\frac{f_{max}\, d}{V} = \text{Constant} \tag{9}$$

(where d is the effective jet nozzle exit diameter in meters). Since V may be assumed to be completely independent of the effects of engine clustering, then the value of f_{max} is inversely proportional to the number (N) of clustered engines, it follows that the thrust is also proportional to the total nozzle exit area (NA) of the engines. Because:

$$\text{Area} = \frac{\pi d^2}{4}$$

$$d = 2\sqrt{\frac{NA}{\pi}}$$

Therefore, d varies as the square root of the thrust and f_{max} is inversely proportional to the square root of the thrust. Actually, the fact that d varies as the square root of the thrust is not only true for clustered engines but is true in general if the expanded jet velocity V is held constant. That is approximately the case for all present and presently contemplated liquid fuel engines and many solid fuel engines also.

By utilizing the above relationships to determine the value of the peak frequency and the increase in sound pressure levels over the smoothed Saturn S-I and F-1 data measured at MSFC, it is possible to calculate the spectra which will result from the testing of vehicles larger than the Saturn S-I. A water-cooled bucket-type deflector similar to the one presently used at the MSFC Saturn test stand must be assumed or else some method devised for correcting the bucket-derived data for the new test stand configuration.

Figure 1 shows a comparison of measured power level spectra for the Saturn S-I and F-1. As can be seen the spectra are identical (within the measurement accuracy) in the overall and the noise spectrum peak as might be inferred from the above discussion. Actually, both spectra are identical across the whole measurement band from 1 to 8000 cycles per second. This again attests to the dependence of the sound generating mechanism upon certain well-defined physical parameters.

It should be emphasized that the overall levels per se are of only very limited usefulness, since the spectra of the noise must be known so that they may be compared with the various criteria, which are themselves functions of frequency. Accordingly, estimates of the noise spectra to be expected have been prepared for smoothed measured sound pressure spectra for the F-1, scaled in thrust and frequency as discussed. These estimated spectra for the 7.5-million-pound thrust S-IC vehicle appear in Figure 2, where the sound pressure levels in octave bands and the calculated overall levels are given for various distances from the source. The levels of Figure 2 pertain to the space average; that is, they give the sound pressure but one which radiates uniformly in all directions. Directivity corrections must be included, as discussed later, if one wishes to estimate the levels to be obtained from the S-IC at a given location.

Careful examination of Figure 2 will show that the spectra presented shift slightly with increasing distance toward lower frequency. This is due to the atmospheric attenuation discussed later.

DIRECTIVITY CORRECTION

Figure 3 presents the assumed characteristic directivity pattern for the single bucket test stand deflector configuration. This pattern has been derived from data from both the large-scale Saturn S-I and F-1 engine tests and from scale model experiments at MSFC. In the full-scale these data are most difficult to obtain since in the acoustic near-field the directivities are distorted. It has been found that beyond one hundred nozzle diameters this directivity remains quite constant. In the full scale experiments, however, this distance is great enough to allow the prevailing meteorological conditions to affect the propagation of sound and, therefore, can sometimes distort the measured directivities. This can be overcome by taking many sets of data under various meteorological conditions. This has been done and Figure 3 represents the best estimate of the characteristic directivity inherent in the use of a single bucket deflector configuration. As reported in Reference 3, this directivity has been found to remain virtually unchanged for propagation paths up to 16 kilometers in length. Data are not presently available beyond this point.

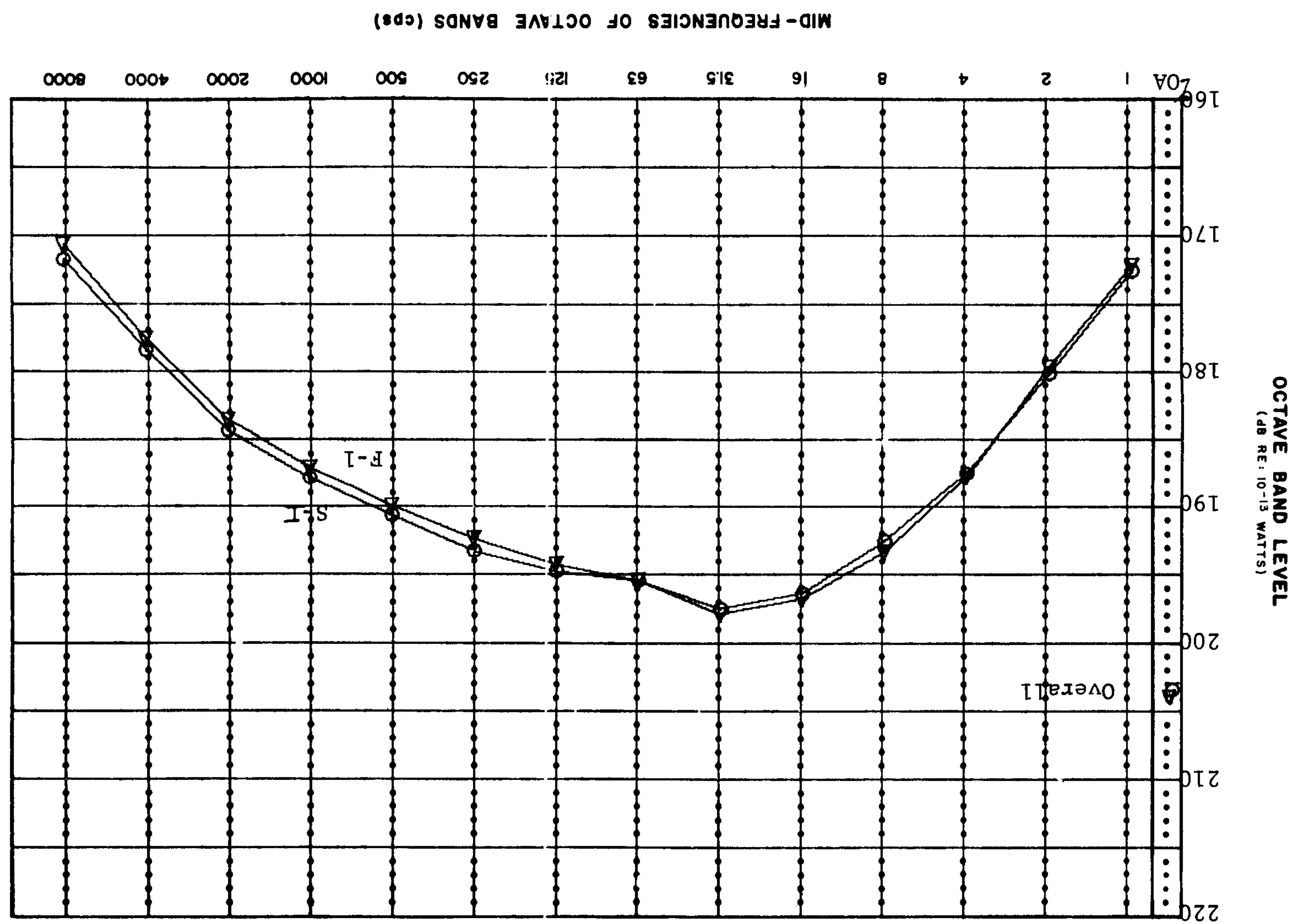

FIGURE 1. COMPARISON OF SOUND POWER LEVELS FROM SATURN S-I AND F-1 STATIC TESTS

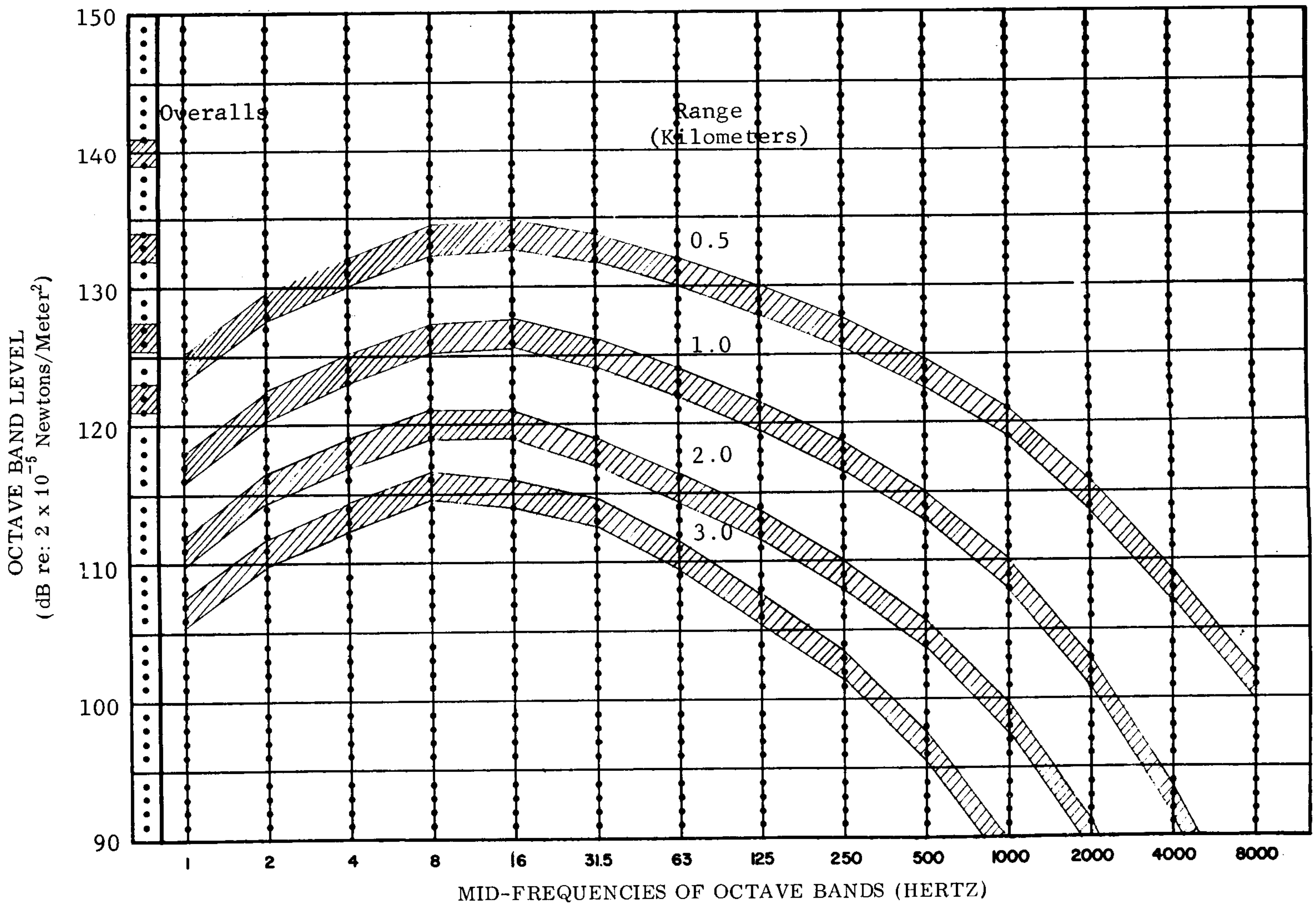

FIGURE 2. ESTIMATED OVERALL AND OCTAVE SOUND LEVELS AROUND THE S-IC STATIC TESTS

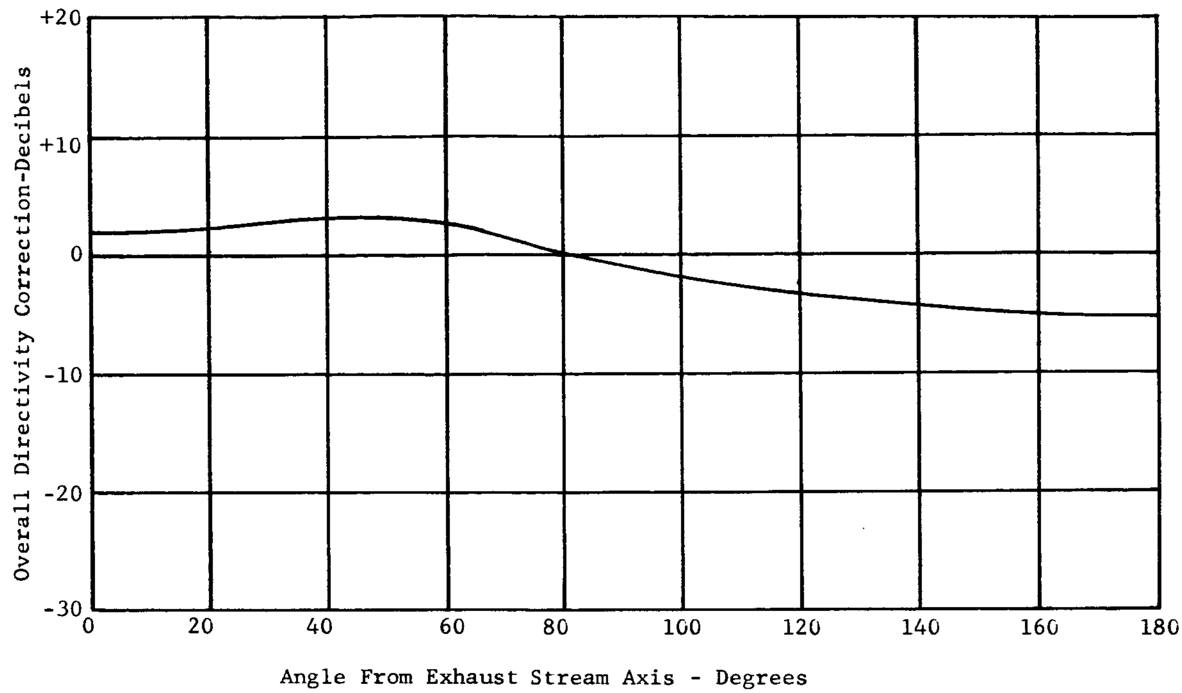

FIGURE 3. MEAN OVERALL DIRECTIVITY PATTERN FOR STATIC TESTS OF LARGE ROCKET ENGINES USING A SINGLE BUCKET DEFLECTOR

To find the overall levels in a given direction, one merely adds algebraically the directivity correction shown in Figure 3 to the average levels of Figure 2. This procedure applies approximately to the octave band levels as well, since experimental data indicates that the Saturn noise spectrum does not change drastically with angular orientation. The spectrum changes that do occur would result in levels that would be generally lower than those predicted by the present procedure. So, this method of calculating overall sound pressure levels may be considered to be conservative in the engineering sense. It should be emphasized that these estimates concern mean values only. Large fluctations are to be expected due to non-homogeneities in the atmosphere itself. (See Ref. 5 for examples and discussion of such fluctuations.)

As an example, consider the following: What is the sound pressure level in the octave band centered around 125 cps in a direction 50 degrees with respect to the exhaust stream, 1.6 kilometers from the S-IC stand? From Figure 2, one finds that the space average sound pressure level in that octave band is approximately 120 dB, re 0.0002 microbar. From Figure 3, one finds that the directivity correction in the 50-degree direction is +3 dB; that is, the actual level is 3 dB above the space average, or 123 dB re 0.0002 microbar. It is to be noted that the directivity pattern permits one to orient the exhaust stream to achieve some noise reduction at critical points. This has been done at MSFC in the planning of the F-1 and Saturn S-IC static test towers to better protect both other government installations in the MSFC-Redstone Arsenal complex and the surrounding civilian areas.

It is appropriate to stress again that in making use of the data shown in Figure 2 (and similar data for other vehicles) one should use the overall level only in a preliminary way, and then only with caution. All criteria, be they for structural damage, deafness, or annoyance, involve a frequency dependence; therefore, it is essential that the spectral character of the noise be considered in the calculation of relevant hazard contours. It is for this reason that the sound pressure spectra are included in Figure 2.

ATMOSPHERIC EFFECTS

Sound propagation along the ground over distances of several kilometers has been shown to be profoundly affected by the state of the atmosphere between source and receiver. Experimental data on sound transmission of rocket noise over long distances, that are well-documented by simultaneously obtained meteorological measurements, have only recently become available largely through the measurement program in progress at MSFC. Moreover, a comprehensive theory is still lacking. Despite this lack of understanding of the physics of sound transmission through the atmosphere, quantitative engineering estimates must still be made. In arriving at these estimates the following procedure has been followed with some success. It is assumed that the total excess attenuation (the difference in decibels between the actual attenuation measured and the level reduction based on inverse-square law alone) measured at a given distance in a given frequency band can be separated into two parts: First, the sum total of dissipative effects in the atmosphere, primarily molecular absorption. Second, the loss (or gain) due to atmospheric refraction, including scattering losses by turbulence and impurities.

Assuming that the excess attenuation effects are separable, it should be observed that the excess attenuation of the first type can be approximated by an attenuation coefficient which is dependent upon distance. This attenuation coefficient also depends not only on the signal frequency but also on bandwidth and spectrum shape. (Estimates of the effective attenuation coefficient are given in Table I). These estimates are based on air-to-ground propagation data[1] obtained from Figure 9-10 in Reference 4 and have been adjusted to take account of the spectrum shape of rocket noise. The attenuation data presented in Reference 5 is based mainly upon an Air Force-Armour Research Foundation study which

---

[1] In air-to-ground propagation over relatively short distances gross sound refraction effects are likely to be small. However their direct application to the ground-level static testing situation has yet to be proved.

showed similar values for low frequency atmospheric attenuation. No allowance was made in these studies for attenuation by ground cover. Although no specific data are available, it is believed that the absorption over open level country with grass and sparse shrubs may be considered to be small at the low frequencies which are important in rocket noise.

Table I

ESTIMATED DISSIPATIVE EXCESS ATTENUATION IN THE ATMOSPHERE

Freq. Band, (cps)	8-16	16-35	35-75	75-150	150-300	300-600	600-1200	1200-2400	2400-4800
Atten. Coef. $\frac{dB}{km}$	1/3	1/3	5/6	1 1/2	2	2 2/3	4	5 1/3	8 1/3

Note: Attenuation Coefficient at very low frequencies ($\approx$ 1 cps) = 0

The estimates of the overall sound pressure levels, the octave band spectra given in the preceding section, were arrived at by using the above figures as "average atmospheric attenuation." Unfortunately, there are few experimental data available against which these estimates can be checked at this time because sound transmission data from static testing of large boosters involve sound refraction as well (see below). However, there are some data which are applicable because the slope of the effective sound velocity profile is small (of the order of one meter/second per kilometer):

(a) Sound pressure spectra from SA-1 Saturn launch. (Ref. 5) The data are applicable because the average gradient of the sound velocity profile at the approximate height was not appreciable.

(The velocity of sound, c, varied less than plus or minus three meters per second per one kilometer altitude.)

(b) Sound pressure spectra during static testing of Saturn at MSFC. There are as yet few spectral analyses of the far-field sound pressures available. However, the spectra measured during test SA-06 (c = 2 meters/sec/km) compare generally with the spectra predicted on the basis of the method outlined in this report.

There is experimental evidence that good correlation exists between the effective attenuation (positive or negative) because of sound refraction and the mean slope (negative or positive) of the effective sound velocity profile with height. (Ref. 7)

The velocity of propagation of sound, c, at a given height, and in a given direction, may be defined as equal to the speed of sound at the temperature at the point in question in still air, and added to it the vector component of the mean wind at that height in the direction considered. As a consequence, the effective velocity of propagation of sound, c, varies not only with height but also with azimuth because of the influence of the wind.

The variations of c with height tend to refract the sound "rays." If the slope of the velocity profile in the atmosphere near the ground between source and receiver is positive, that is, if the effective speed of propagation of sound increases with height, the sound "rays" are bent toward the ground. This may result in the formation of a sound "focus", or large negative values of excess attenuation. If the slope of the velocity profile is negative, the sound "rays" are bent upward, away from the ground. This may result in the formation of a sound "shadow", or large positive values of excess attenuation. (Ref. 7 & 8)

CRITERIA FOR EVALUATING ANTICIPATED SOUND PRESSURE LEVELS

There are several possible approaches to evaluating the anticipated sound pressure levels. Some previously suggested criteria (Ref. 6) are given in terms of maximum permissible overall sound pressure level without regard to the spectral composition of the generated noise. However, it is felt best to use building and personnel damage criteria expressed in terms of sound pressure level given in band sound pressure levels not to be exceeded.

The above-mentioned criterion based on overall sound pressure level indicated that residential building structures may suffer damage when they are exposed to noise with an overall sound pressure level exceeding 120 dB re 0.0002 microbar. This criterion was established essentially for one specific purpose: to estimate what damage might occur in the residential areas surrounding the Kennedy Space Center during launches of Nova vehicles in support of the Apollo program. Thus,. the overall SPL criterion was intended to apply primarily to existing residential buildings located outside the controlled area, and was designed to aid in balancing the costs of damages against the cost of land acquisition.

For the purposes of this report, however, the author is interested not only in the residential areas outside the controlled zone, but also in the effects of static tests upon structures and personnel in the controlled zone, itself. Moreover, the range of interest is not just serious damage but also minor damage and community annoyance. Since these criteria are dependent upon the frequency spectrum of the noise, it is more appropriate to use damage criteria in which frequency information is retained.

It is well known that structures are most likely to be damaged by noise when they are excited at a resonance and that the lowest resonance is usually associated with the greatest damage-causing potential. For example, a wall or a window which may be damaged by noise with a 120 dB octave band sound pressure level in a band encompassing its fundamental frequency may be able to withstand levels up to 126 dB in the next higher octave band. This assumes that the higher octave band encompasses higher resonance frequencies of the structures considered; if not, then this band only excites modes of resonance and its damage causing potential is reduced.

Residential structures outside controlled areas may have components (walls, window, roof panels) with all sorts of values of fundamental resonant frequencies. Thus, communities of reasonable size may be expected to harbor some structures with fundamental frequencies that will fall within the octave band corresponding to the peak of the noise spectrum generated by any given large booster. The overall levels associated with rocket noise depend, for all practical purposes, only on the three or four octave bands nearest the spectral peak (the spectrum shapes near the peaks do not vary greatly). Therefore, establishment of an overall level criterion is essentially establishing an octave band criterion for structures (with some assumed average thickness and strength characteristics) with resonances that fall near the spectral peak.

Detailed discussions of the derivation of the appropriate frequency-dependent criteria, as well as estimates of the applicable numerical values and comparison with field data, are presented in Reference 9. Additional experiments conducted by NASA in relation to sound-induced window damage, recently reported by Freynik (Ref. 10), lend further credence to these criteria.

The heavy solid curve of Figure 4 represents the maximum octave band sound pressure levels to which personnel without ear protection may, on the average, be exposed for up to three minutes per day without suffering appreciable hearing loss. This proposed deafness criterion concerns only the effect of the noise on the threshold of hearing of the subjects. During the recent laboratory tests from which the above criteria were derived (see below), the sound was applied only to the ears of the subjects (by means of earphones) without exposing the entire body. This, of course, is not the case when a person is exposed to

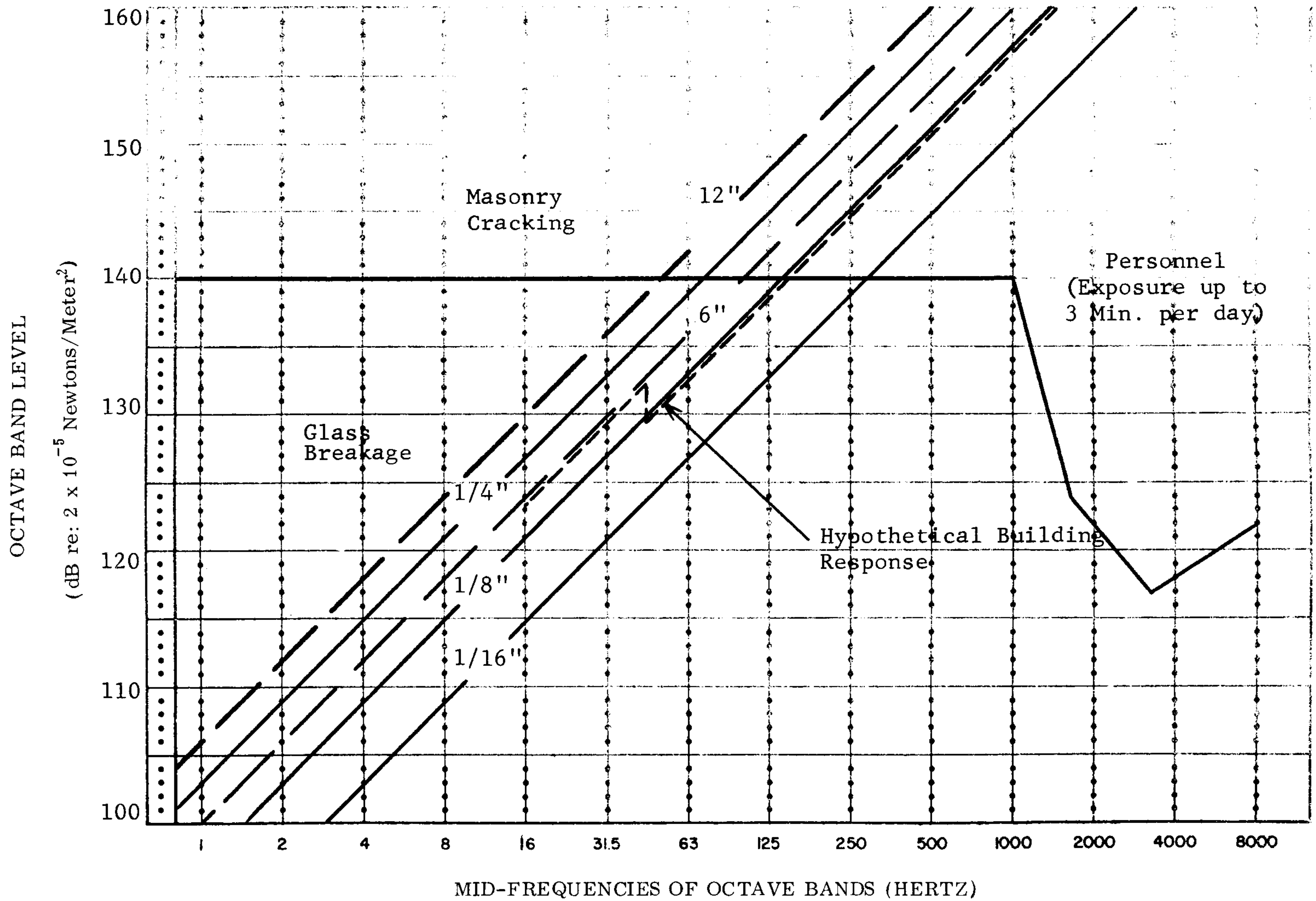

FIGURE 4. NOISE EXPOSURE CRITERIA FOR BUILDING STRUCTURES AND UNPROTECTED PERSONNEL

rocket noise outdoors. Neither does this criterion take into consideration such effects as surprise (startle response) or impairment of a person's ability to perform mental or physical tasks (such as driving vehicles).

The hearing loss criterion presented here is associated with a temporary hearing threshold shift of 10 dB at 1000 cps and of 20 dB at 4000 cps, as measured two minutes after exposure. It is based on the "95 dB re threshold" damage risk criterion of Figure 2 of Kryter, Weisz, and Wiener (Ref. 11), plus the assumption that no octave band noise level should ever exceed 140 dB. Although the proposed criterion permits higher levels than those specified by Air Force Regulation AFR 160-3, it is believed to be conservative because of the predominant low frequency character of the noise. Corrections for exposure duration were made after Ward, Glorig, and Sklar.

The light solid lines of Figure 4 indicate the maximum SPL when windows tend to behave like simple supported panels. Thus, fundamental frequency f_1 of a window may be obtained from the following relation:

$$f_1 \text{ (cps)} = 700h\,(a^{\frac{1}{2}} + b^{\frac{1}{2}}) \qquad (10)$$

where h = window thickness, in.

a = window height, ft.

b = window width, ft.

One should note that these criteria pertain to conventional or "average" structures, and that nonconventional design (such as the use of laminated glass, sand-filled cinder blocks) may result in configurations able to withstand much higher sound pressure levels than those shown in Figure 4.

Consider, for example, a building with 6-inch thick cinder block walls and double strength (1/8 in. thick) windows, where the largest window is 2 ft x 2 ft (f_1 45 cps), and the largest wall is 10 ft x 20 ft (f_1 20 cps). By choosing the lowest of the applicable criterion curves, recalling that each is to be used only above the corresponding fundamental frequency, one obtains the composite criterion labeled "hypothetical building" in Figure 4. Note that here the masonry criterion controls below 45 cps, since the window criterion applies only above 45 cps.

Figure 5 shows hazard contours applicable to the static firing of 7.5 million-pound thrust S-IC boosters into a watercooled single bucket deflector. These contours were obtained by comparing the predicted spectra with the criteria of Figure 4 and provide an idea how far structures or unprotected personnel should be kept from the S-IC test stand.

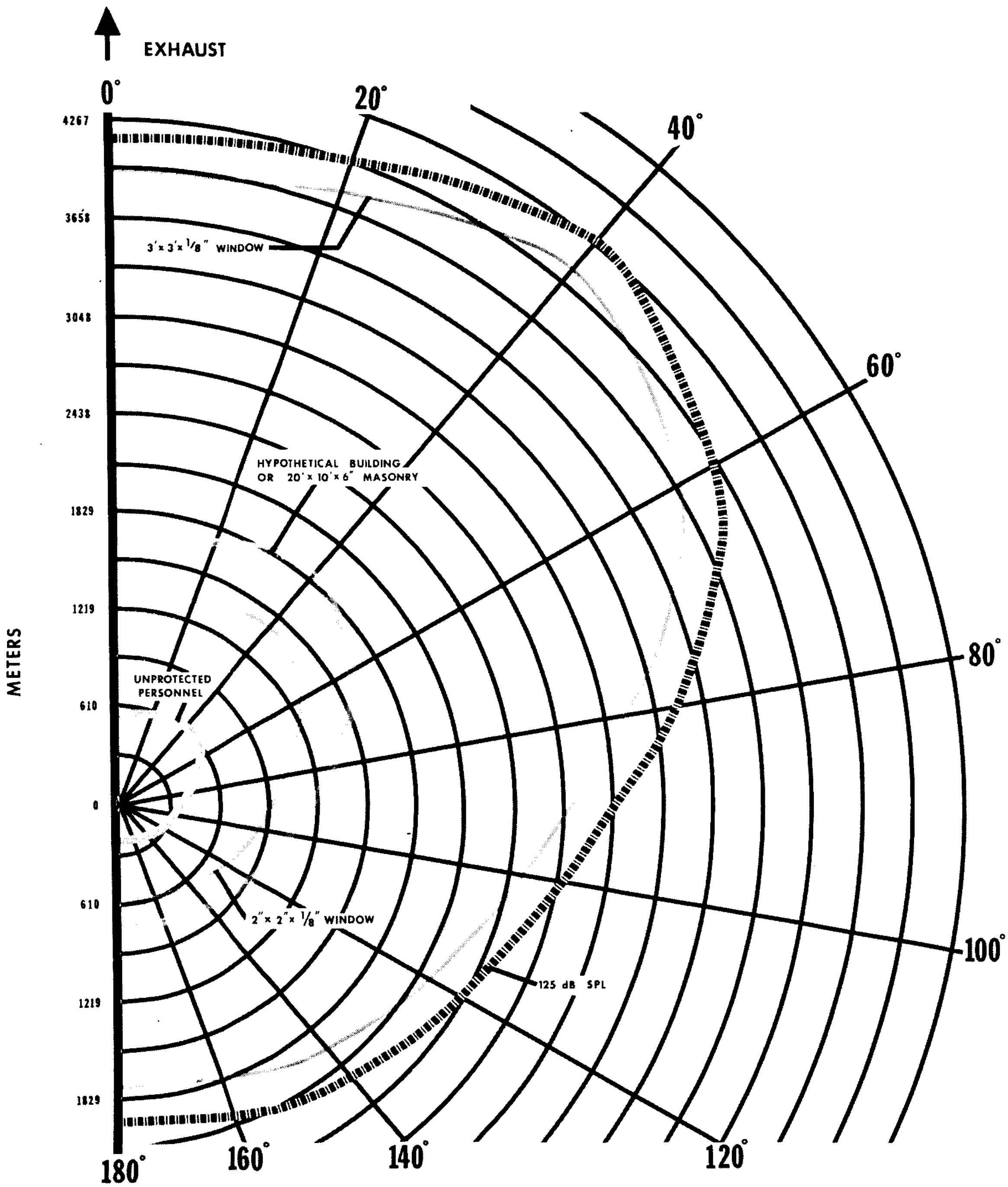

FIGURE 5. ACOUSTICAL HAZARD CONTOURS: S-IC (7.5 x 10^6 Lb. THRUST) FIRING INTO SINGLE BUCKET DEFLECTOR

Also shown in Figure 5 is the estimated contour corresponding to a 125 dB overall sound pressure level, as obtained from Figure 2. It is evident that use of a 125 dB overall sound pressure level criterion in the present case would be over-conservative for nearly all types of structures one would reasonably consider for a test site.

In view of the frequency dependence of the damage criteria, it is clear that an overall sound pressure level criterion cannot be very useful by itself, since it discards all spectrum information. Thus, for example, an overall sound pressure level of 105 dB obtained from Saturn S-I contains more high frequency energy than the same level from S-IC. Consequently, although both spectra would be represented by the same overall level, the S-IC's spectrum would result in a greater hazard to structures with low resonances, whereas Saturn I's would be greater hazard to personnel (since hearing is more likely to be impaired by higher frequencies).

CALCULATED FAR-FIELD LEVELS

The methods outlined in the earlier sections of this report have been applied to the calculation of the sound pressure levels which may be expected in the far-field from static tests of the seven and one half million pounds thrust Advanced Saturn S-IC. These predicted levels and their associated spectra are shown in Figure 2, as previously mentioned. However, there is no directivity to this figure, and therefore it can be used in only a general way. Figure 5 shows the effects of this directivity out to about four and one quarter kilometers (2.5 miles) range. The levels, in the form of isopleths (contours), are shown around the static test stand for certain arbitrary building configurations. Also shown is the 125 decibel contour. It should be noted that this figure is oriented with reference to the flame exhaust (deflector) direction.

In Figure 6, the 120 and 110 decibel predicted contours, assuming a homogeneous atmosphere, are presented superimposed upon a map of the Redstone Arsenal area. As can be seen the sound pressures on the Arsenal, while high, are not unusual nor dangerous outside the test area. One reason for this is that the directivity associated with a single bucket deflector was taken into account when the test stand was oriented. Thus, toward the main portions of the Arsenal and the city of Huntsville, the Advanced Saturn S-IC will not present a larger acoustic problem than the S-I. This shall be changed at longer ranges because of the added low frequency content of the acoustic signal from the S-IC. The S-IC noise will attenuate less and will therefore eventually be somewhat larger than the levels at the same location from the S-I tests.

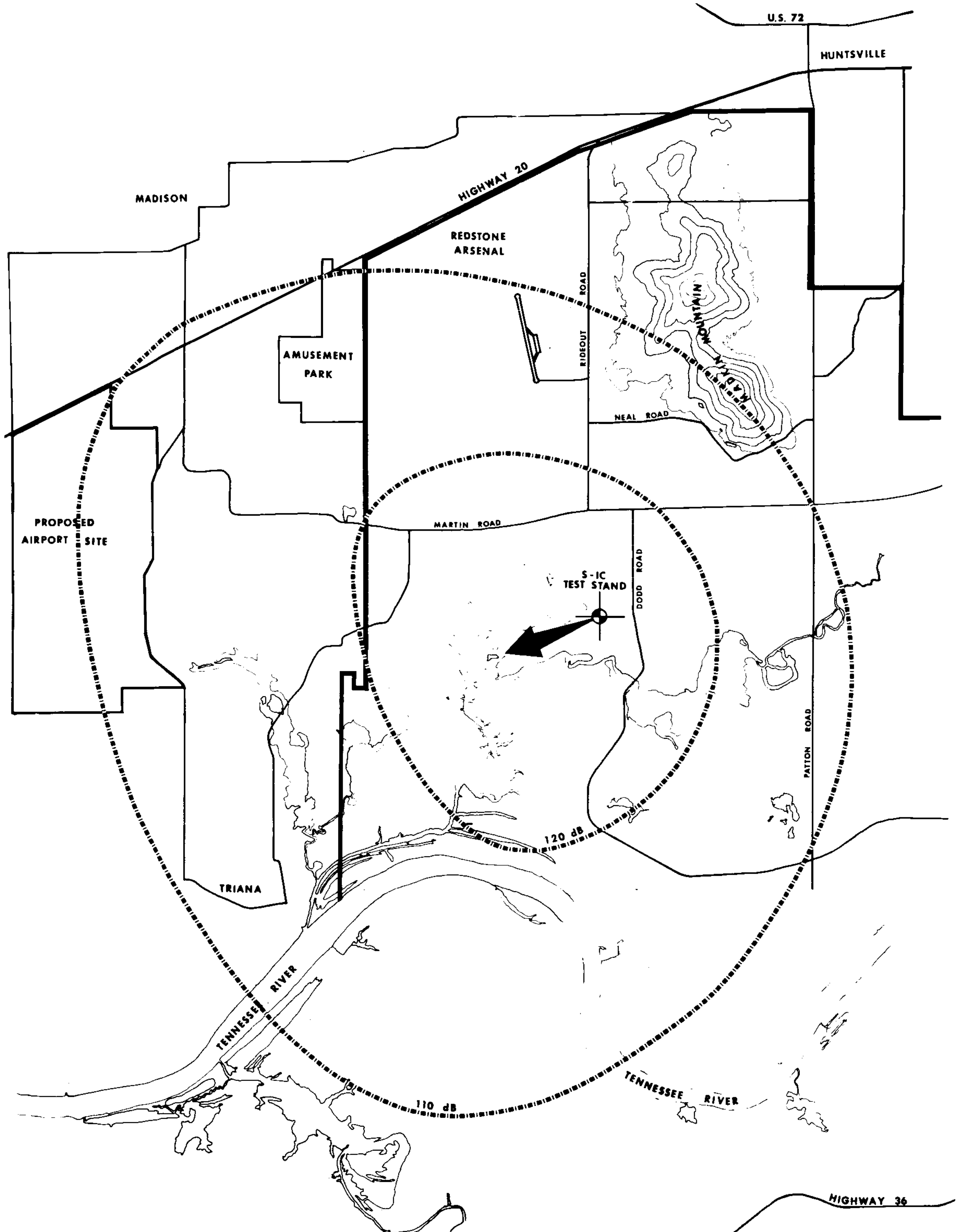

FIGURE 6. ANTICIPATED 120 AND 110 DECIBEL CONTOURS AT MSFC

In Figure 7 the calculated difference between the S-I and S-IC sound pressure levels is shown. This curve represents the variation in level as a function of range out the 45 degree azimuth from the S-IC test stand at MSFC. Since the S-I test stand is oriented toward Huntsville along this azimuth while the S-IC stand is pointed away, there is actually a small decrease (2 decibels) in apparent sound pressure level at the source. Added to that is the effect resulting from the S-I stand being 0.75 kilometers closer to Huntsville. The net result is that along this one azimuth the S-I is predicted to be louder for the first seven kilometers than the S-IC. Beyond this point the reverse is true because of the difference in attenuation rates.

The S-IC fires toward the west-southwest and, as one might expect, more of the acoustic energy is directed toward the western boundary of Redstone Arsenal. However there is a buffer of about four kilometers of unused swamp between the stand and the western boundary. For this reason the anticipated 120 decibel contour remains on government property. However the 110 decibel contour is about another four kilometers to the west of that. (See Figure 6) Therefore, the newly-developing areas immediately to the west of the Arsenal could be exposed to sound pressure levels which would be in excess of the generally accepted threshold of annoyance.

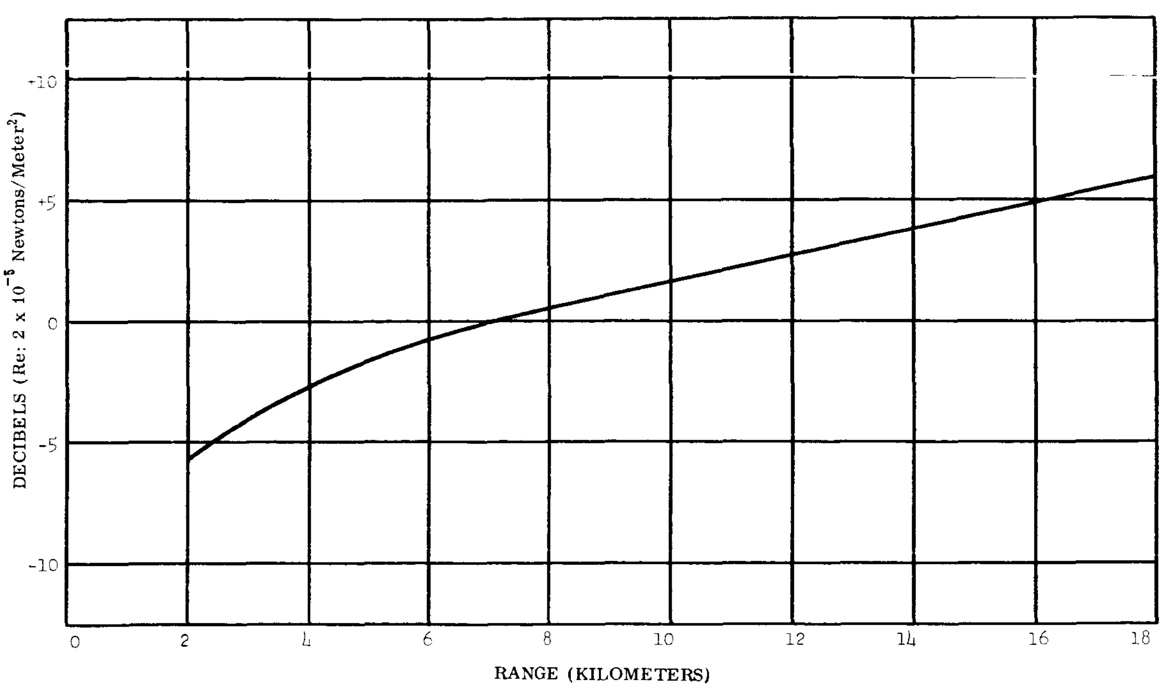

FIGURE 7. ESTIMATED INCREASE IN SPL (MSFC, 45° AZIMUTH) OVER S-I LEVELS WHICH MAY RESULT FROM S-IC FIRING

It is anticipated that by firing the S-IC under meteorological conditions more favorable than those assumed, an additional five to ten decibels of noise reduction can be achieved. Since such conditions normally occur in the MSFC area out the azimuth in the third and fourth quadrants and since much of the land in those areas is unused, it is anticipated that acoustical problems to the west will be minimal. By a careful choice of firing conditions it should be possible to protect the various areas surrounding the MSFC S-IC test site from unfavorable sound pressure levels.

At this point it again should be mentioned that certain assumptions were made in the calculation of the sound levels and spectra presented herein. The applicability of these assumptions to any other test configuration need to be carefully considered before the figures from this report are used in another context.

CONCLUSIONS

The acoustical problems to be faced at Marshall Space Flight Center during the static test firings of the S-IC space vehicle are only slightly larger than those under which the Saturn S-I has been successfully tested many times. Toward the major population center there will be little increase in the overall sound pressure level and a shift of only one octave downward in frequency. While it may be anticipated that Huntsville will be made aware by the noise of such testing, there is no reason to expect or to fear that there will be any serious damage or basis for claims against the government. Most of the Army installations at Redstone Arsenal have already been exposed numerous times to similar (or higher) sound pressure levels from tests of the S-I and F-1 static firings.

The areas west of the Arsenal boundary will not have the benefit of the directivity of the source as does Huntsville. However it can be expected that it will be possible to take advantage of the prevailing winds and receive about ten decibels of noise reduction due to the energy being refracted harmlessly upward.

It is possible that small damage may be sustained in nearby MSFC areas and precautions should be taken to insure that personnel in the vicinity of the test area are adequately protected. Again it is not expected that these results of S-IC testing will vary materially from those experienced during S-I and F-1 static tests.

REFERENCES

1. Tedrick, R. N., "Calculation of the Far-Field Acoustic Effects of Static Testing of Large Space Vehicles", MSFC Report MTP-TEST-63-3, 1963.

2. Tedrick, R. N., "Anticipated RMS Sound Pressure Levels Around Static Tests of Large Vehicles," MSFC Report MTP-TEST-61-20, 1961.

3. Tedrick, R. N., "Acoustical Measurements of Static Tests of Clustered and Single Nozzled Rocket Engines," Technical Paper Presented at Acoustical Society of America Meeting, New York, May 1964.

4. Beranek, L. L., Editor, "Noise Reduction," McGraw-Hill, 1961.

5. Dorland, W. D. and Tedrick, R. N., "Results of Acoustical Survey of SA-1 Launch," MSFC Report MTP-TEST-62-2, 1962.

6. Joint Air Force--NASA Hazards Analysis Board "Safety and Design Considerations for Static Tests and Launch of Large Space Vehicles," Section II-B Acoustic (Tech. Reviewer H. Von Gierke), NASA, June 1961.

7. Tedrick, R. N. et al, "Studies in Far-Field Acoustic Propagation," NASA Tech. Note D-1277, 1962.

8. Beranek, L. L., "Acoustic Measurements," John Wiley and Sons, 1949.

9. Dyer, I. and Wiener, F., "Response and Fatigue in Complicated Structures," Journal of Acoustical Soc. Am. 33, 1662, 1961.

10. Freynik, H. S., "Response of Windows to Random Noise," Journal of Acoustical Soc. Am. 34, 720, 1962.

11. Kreyter, Weisz, and Wiener, "Auditory Fatigue From Audio Analysis," Journal of Acoustical Soc. Am 34, 383, 1962.

PREDICTED ACOUSTIC EFFECTS AT MSFC OF THE STATIC TEST FIRING OF THE ADVANCED SATURN S-IC

By

Richard N. Tedrick

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This report also has been reviewed and approved for technical accuracy.

Karl L. Heimburg

Karl L. Heimburg
Director, Test Laboratory